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GB 1171626
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(54) **Improvements in or relating to microwave transmission systems**

(57) Antenna elements 44 are fed from a lesser number of controllable phase shifters 42 to enable a microwave beam to be swept over an arc, each element being fed from more than one phase shifter. This allows undesirable side lobes to be minimised, whilst requiring relatively few expensive controllable phase shifters. The invention is applied to an aircraft landing system.

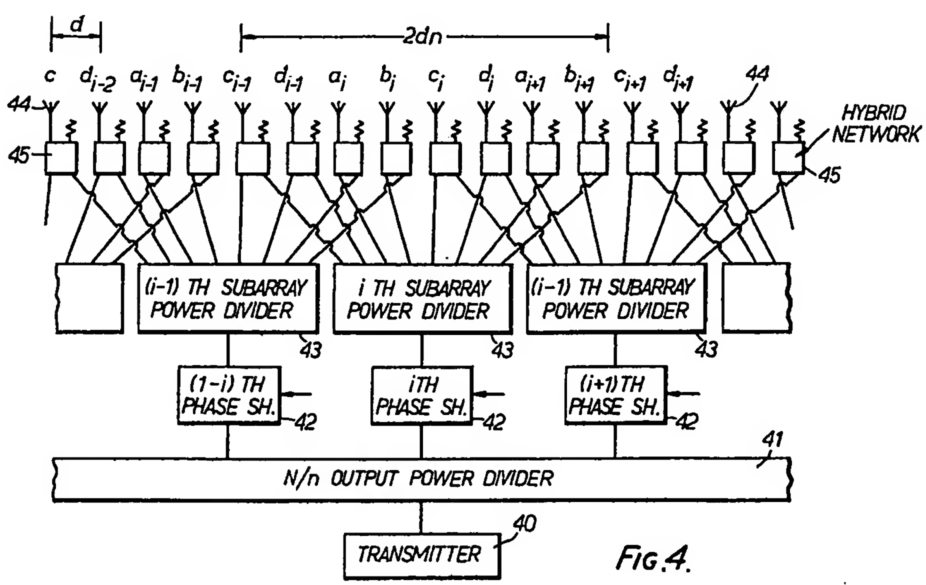

FIG.4.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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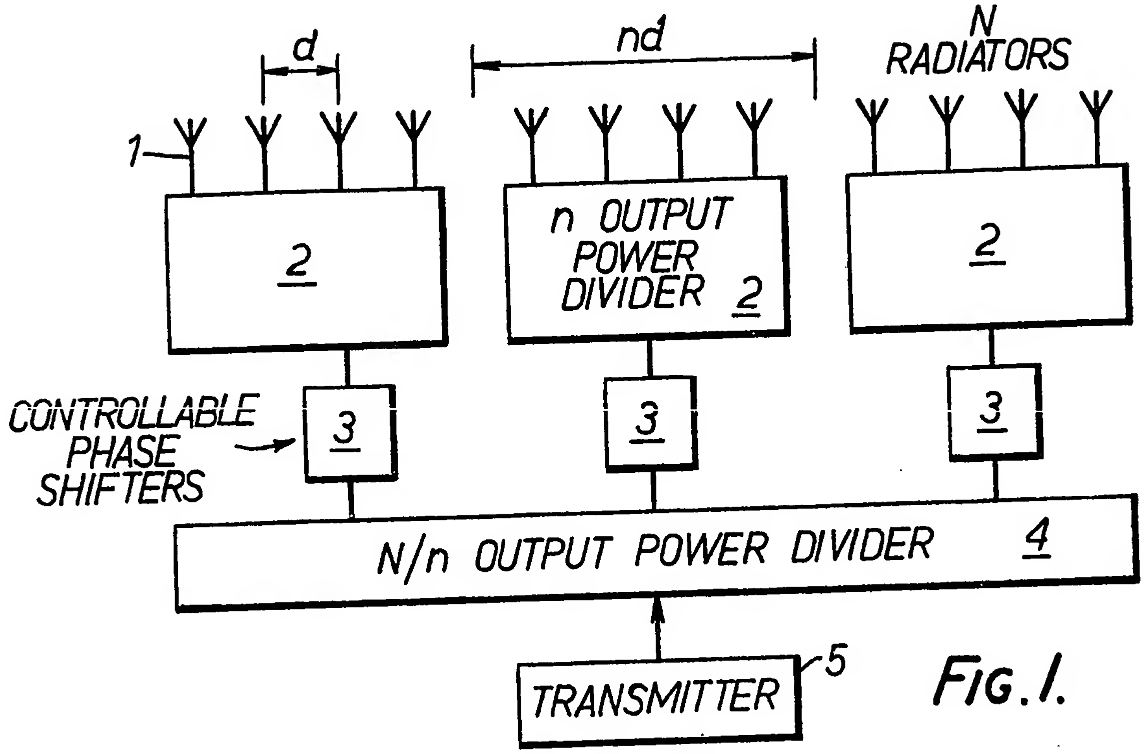
d
nd
N RADIATORS
1
n OUTPUT POWER DIVIDER 2
2
2
CONTROLLABLE PHASE SHIFTERS
3
3
3
N/n OUTPUT POWER DIVIDER 4
TRANSMITTER
5

FIG.1.

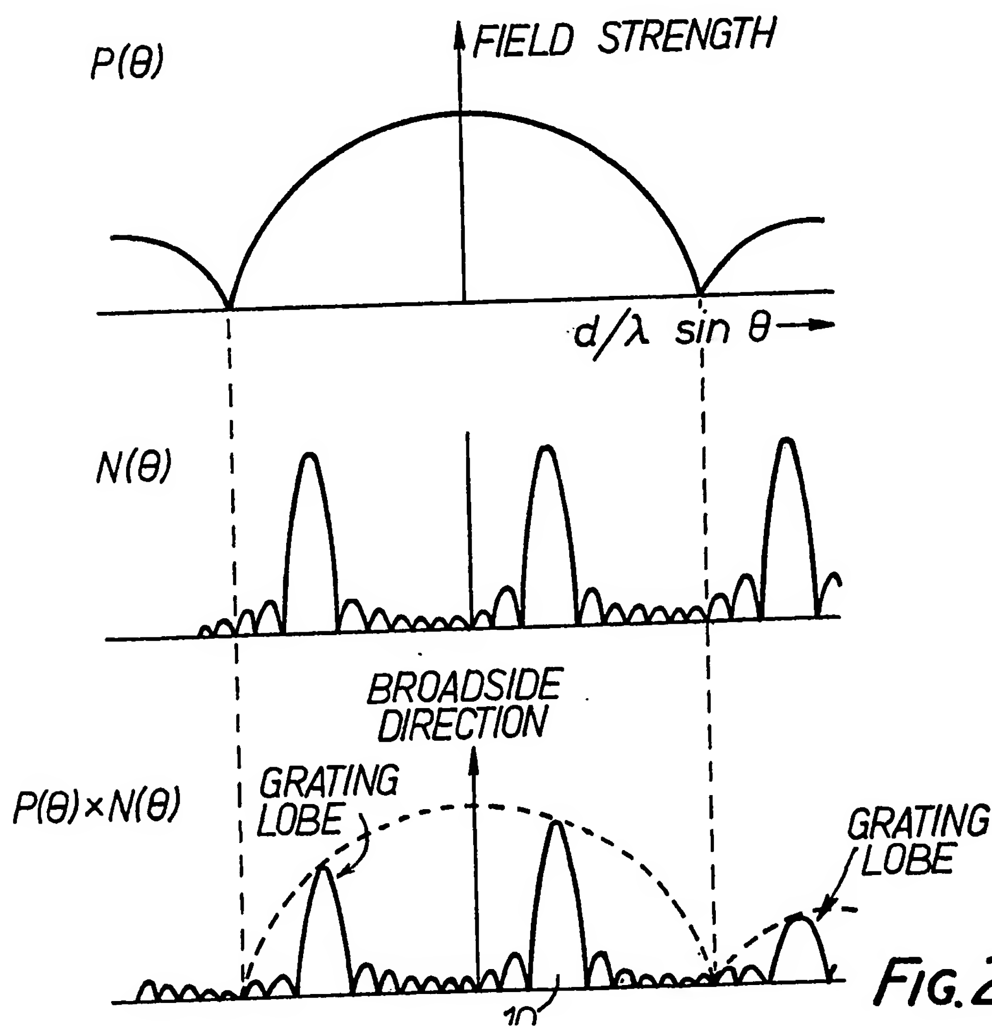
P(θ)
FIELD STRENGTH
d/λ sin θ
N(θ)
BROADSIDE DIRECTION
P(θ)×N(θ)
GRATING LOBE
GRATING LOBE
10

FIG.2.

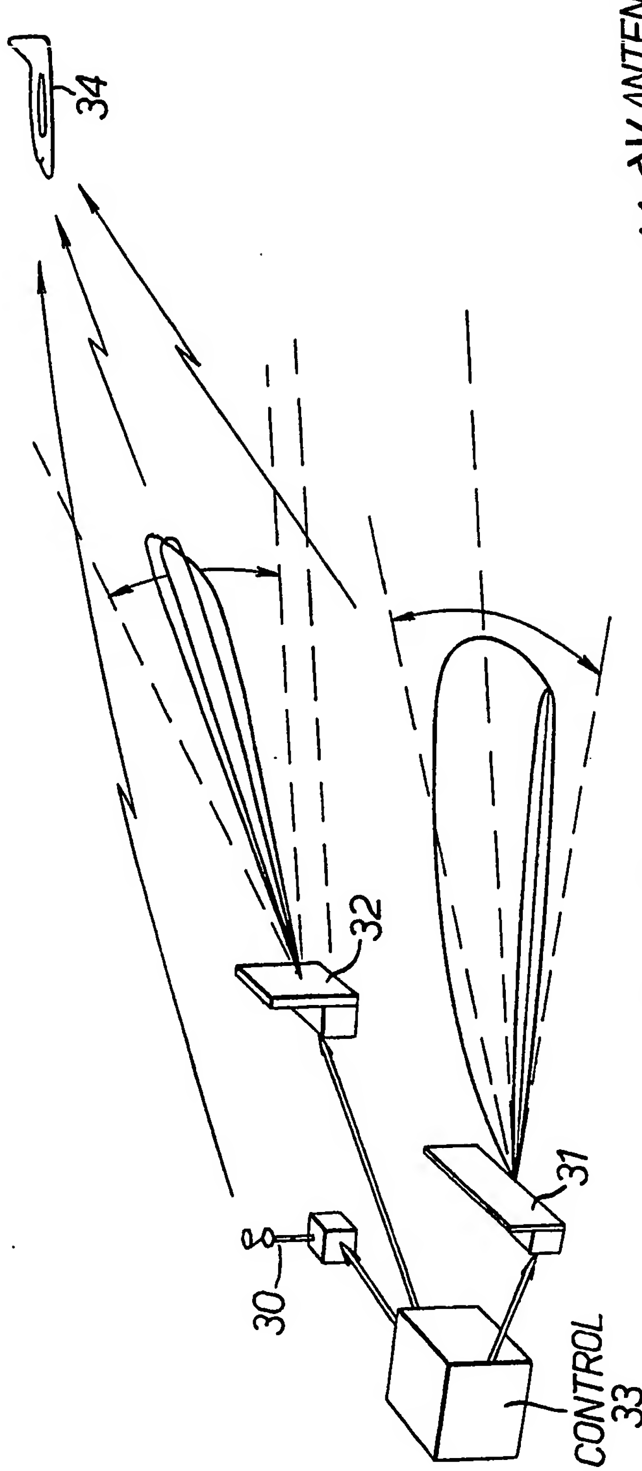
34
32
31
30
CONTROL
33

FIG. 3.

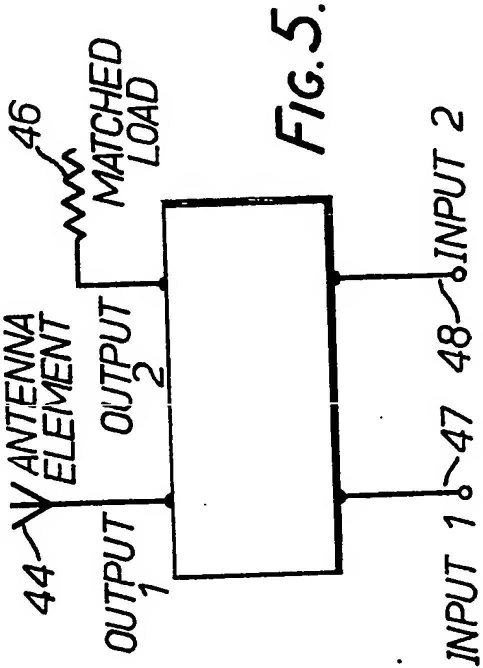
46
MATCHED
LOAD
44
ANTENNA
ELEMENT
OUTPUT
2
OUTPUT
1
INPUT 2
48
47
INPUT 1

FIG. 5.

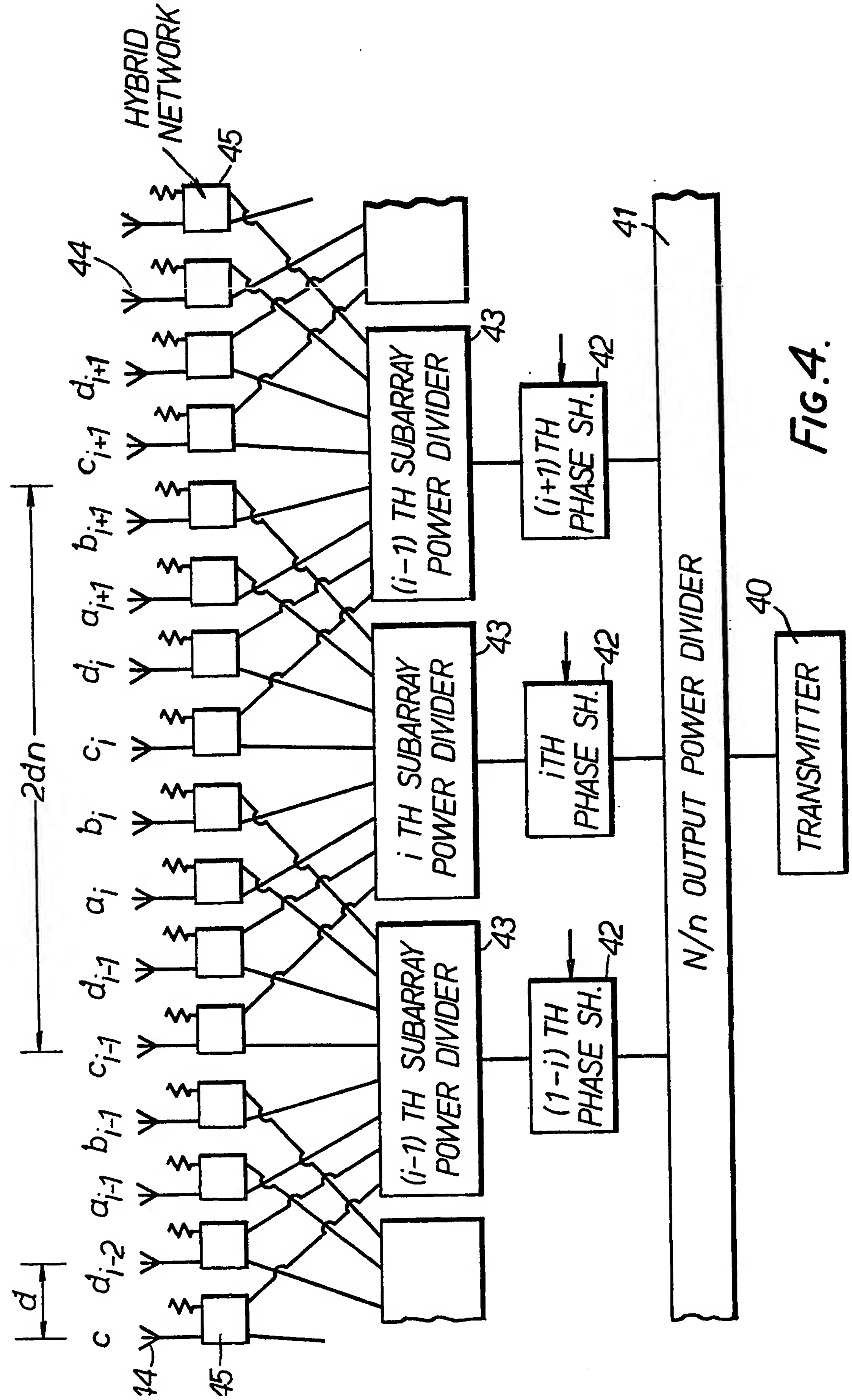
HYBRID NETWORK
45
44
41
43
42
d_{i+1}
c_{i+1}
b_{i+1}
a_{i+1}
d_i
c_i
b_i
a_i
d_{i-1}
c_{i-1}
b_{i-1}
a_{i-1}
d_{i-2}
c
d
2dn
(i−1) TH SUBARRAY POWER DIVIDER
i TH SUBARRAY POWER DIVIDER
(i−1) TH SUBARRAY POWER DIVIDER
(i+1)TH PHASE SH.
iTH PHASE SH.
(1−i) TH PHASE SH.
N/n OUTPUT POWER DIVIDER
40
TRANSMITTER
44
45

FIG. 4.

SPECIFICATION

Improvements in or relating to microwave transmission systems

This invention relates to microwave transmission systems of the kind which use a number of individual antenna elements to produce a directional radiation beam of microwave energy. The need can arise to steer the beam, that is to say, to sweep the beam across an arc of space in a controlled manner, and this requirement can result in a complex and expensive microwave system in which a very large number of controllable phase shifters are used to control the direction of the beam. For example, in an earlier proposed microwave transmission system each individual antenna element has been provided with its own controllable phase shifter.

In a microwave landing system in which the directional microwave beam is used to assist the movement of aircraft in the vicinity of an airport the need arises to produce a microwave beam which can be accurately scanned at a precise rate across a predetermined arc of space, and the present invention seeks to provide a microwave transmission system which is suitable for this purpose, but which does not require an excessive number of expensive individual controllable phase shifts.

According to this invention a microwave transmission system includes a plurality of antenna elements, means for feeding microwave energy to said elements via a plurality of phase shifters which are coupled to said elements, the output of each phase shifter being arranged to feed a plurality of antenna elements and each antenna element receiving energy from at least two phase shifters whereby the phase delays introduced by the phase shifters determine the direction of a beam of microwave energy radiated by said antenna elements.

Thus in contrast to earlier arrangements, each antenna elements transmits at least two microwave signals which are not in phase, and which are fed to it by at least two different controllable phase shifters. This enables the number of controllable phase shifters to be minimised, whilst avoiding the generation of unacceptable side lobes associated with the directional microwave beam.

Preferably the antenna elements are arranged in a linear array, the number of antenna elements being an integral multiple of the number of phase shifters which are coupled to them.

Preferably again the power fed to a group of adjacent antenna elements from a given phase shifter is provided with an amplitude taper so that more power is fed from the phase shifter to the antenna element or elements at the centre of the group than is fed to the outer antenna elements of the group.

The invention is further described by way of example with reference to the accompanying drawings in which,

Figure 1 illustrates a known microwave transmission system which suffers from the disadvantage of generating unacceptably large side lobes,

Figure 2 shows the radiation pattern produced by such a system,

Figure 3 illustrates an aircraft landing system of the kind to which the present invention is applicable,

Figure 4 illustrates a microwave transmission system in accordance with the present invention and

Figure 5 shows a portion thereof in greater detail.

Referring to Figure 1, a known system includes a plurality of antenna elements 1 are divided into sub-arrays, each sub-array being fed from a power divider 2 so that each antenna element 1 in a sub-array receives the same power level. Each power divider 2 is fed via a controllable phase shifter 3 and a further power divider 4 from a transmitter 5, which includes a source of microwave power. Assuming that there are N individual radiating antenna elements and that each sub-array contains *n* antenna elements the power divider 4 provides at each of its N/n outputs a proportion N/n of the power fed to it from the transmitter 5. The spacing between adjacent antennas is *d* and the resulting radiation patterns are illustrated in Figure 2, in which field strength is plotted against

$$\frac{d \sin \theta.}{\lambda}$$

The overall radiation pattern is given by the product of P(θ) and N(θ), where P(θ) is the sub-array pattern and N(θ) is the array factor. Figure 2 illustrates these radiation patterns for the case when the main directional beam 10 is displaced from the broad side direction so that grating lobes, which are undesirable side lobes, are generated. These grating lobes disappear when the main directional beam 10 is pointing in a broad side direction, but they become progressively larger as the angle over which the directional beam is scanned increases. Thus even though an antenna arrangement of the kind shown in Figure 1 requires fewer controllable phase shifters than the system referred to previously, in which each radiating element was provided with its own controllable phase shifter, the level of performance obtainable in this way is not suitable for certain applications.

The present invention is particularly suitable for use with an aircraft landing system of the kind referred to as the Time Referenced Scanning Beam Microwave Landing System (TRSB MLS). An aircraft landing system of this kind illustrated diagrammatically in Figure 3. The airfield based equipment includes an omnidirectional antenna 30, a phase scanned azimuth antenna 31 having a narrow azimuth beam and a phase scanned

elevation antenna 32 having a narrow elevation beam. Under the control of a central control unit 33, the omnidirectional antenna 30 transmits a predetermined signal format and a time reference to aircraft 34 within range during a time interval T0 to T1. The elevation antenna 32 scans its beam from 0° to θ_e° and back in the time interval T2 to T3 which is specified in the signal format, and the azimuth antenna 31 scans its beam from -θ_a° to +θ_a° and back in the time interval T4 to T5 which again is specified in the signal format. The aircraft 34 contains equipment which records the times at which it is illustrated by the elevation antenna beam within the time interval T2 to T3 and from this aircraft elevation bearing with respect to the airfield is computed. Similarly by recording the times at which it is illuminated by the azimuth antenna beam, the aircraft azimuth bearing with respect to the airfield can be computed.

The correct determination by the aircraft of its azimuth and elevation bearings depends on the properties of the elevation antenna beam and the azimuth antenna beam, since for unambiguous operation it is necessary that the side lobes produced by the two antennas should be below the threshold of detection by an aircraft. For this reason the radiation pattern of the kind illustrated in Figure 2 is unacceptable.

Figure 4 shows part of a microwave transmission system in accordance with the present invention which is suitable for use with a TRSB MLS which enables the amplitude of side lobes to be kept to acceptable levels without requiring the excessive use of controllable phase shifters. In practice two of the arrangements shown in this Figure would be provided, one for elevation and the other for azimuth. A transmitter 40 generates a microwave signal which is passed to an N/n output power divider which feeds equal powers to controllable phase shifters 42. Each phase shifter 42 is connected to a sub-array power divider 43 which in turn is coupled to eight antenna elements 44, via hybrid networks 45. Each hybrid network 45 is arranged to provide two output amplitudes in the ratio of two to one. A hybrid network is shown diagrammatically in Figure 5 in which an antenna element 44 and a matched load 46 are connected to respective outputs 1 and 2, whereas respective ones of a pair of input terminals 47 and 48 are connected to appropriate different sub-array dividers 43. When an input of given amplitude is applied to input 47, a signal is applied to the antenna element 44 which is twice the amplitude of the signal applied to the matched load 46, and this is the converse of the situation obtained when the input signal is applied to input terminal 48. Thus it can be seen that a given sub-array power divider 43 excites eight antenna elements with relative amplitudes of ½, ½, 1, 1, 1, 1, ½, ½. In order to ensure any phase excitation of the eight antenna elements the differential phase shift produced by the hybrid networks is correct by adjusting the transmission line lengths between the sub-array power divider outputs and the hybrid network inputs. Hybrid networks having the required properties are well known, and so they are not described here in greater detail.

This method of excitation of the antenna elements 44 allows the effective apertures of adjacent sub-arrays of the elements to overlap. For example, the i^{th} sub-arrays power divider is connected to antenna elements a_{i+1} and b_{i+1} which are also fed from a $(i+1)^{th}$ sub-array power divider. The effect on the radiation patterns is that the large sub-array aperture enables the sub-array patterns to be controlled so as to suppress grating lobe levels as the main beam scans away from the broadside direction. The sub-array pattern for arrays of waveguide horn radiators is given approximately by

$$P(\theta) = \frac{\sin\left(\frac{2\pi d \sin\theta}{\lambda}\right)}{\left(\frac{2\pi d \sin\theta}{\lambda}\right)} \left[\cos^3\left(\frac{2\pi d \sin\theta}{\lambda}\right) - \tfrac{1}{4}\cos\left(\frac{2\pi d \sin\theta}{\lambda}\right)\right]$$

In order to maintain the grating lobe level below, say −20 dB, relative to the main beam at broadside, the grating lobe can occur anywhere outside the angle θ_g given by $\left(\frac{2d \sin\theta_g}{\lambda}\right) = 0.3$. Hence the main beam angle θ_o is defined by

$$\frac{4d}{\lambda}\left|\sin\theta_o\right| + \frac{4d}{\lambda}\left|\sin\theta_g\right| = 1,$$

so that

$$\frac{d}{\lambda} \leq 1/(10\sin\theta_o)$$

In order to provide a main beam scan of ± 10° from broadside whilst maintaining the grating lobe level below −20 dB relative to main beam of d ≤0.6λ the element spacing limits for a range of main beam scans is given below, together with the number of phase shifters (N/4) necessary for an antenna having a 2° beamwidth.

Main Beam Scan	Element Spacing	No of Phase Shifters
5°	1.15λ	7
10°	.58λ	13
15°	.39λ	20
20°	.29λ	26
25°	.24λ	32
30°	.20λ	38
35°	.17λ	43
40°	.16λ	48

The number of radiating elements in the sub-array aperture can be varied and in general the minimum number will result in the most cost effective design and in practice may be desirable to use half the number of antennas coupled to a sub-array power divider as those shown in Figure 4.

The microwave beam is caused to scan across a predetermined arc of space by progressively altering the phase shift introduced by each controllable phase shifter 42. In practice, means, not shown, control all controllable phase shifters cyclically so that the microwave beams scan backwards and forwards at a precisely predetermined angular rate between predetermined angular limits.

CLAIMS

1. A microwave transmission system including a plurality of antenna elements, means for feeding microwave energy to said elements via a plurality of phase shifters which are coupled to said elements, the output of each phase shifter being arranged to feed a plurality of antenna elements, and each antenna element receiving energy from at least two phase shifters whereby the phase delays introduced by the phase shifters determine the direction of a beam of microwave energy radiated by said antenna elements.

2. A microwave transmission system as claimed in claim 1 and wherein the antenna elements are arranged in a linear array, the number of antenna elements being an integral multiple of the number of phase shifters which are coupled to them.

3. A microwave transmission system as claimed in claim 1 or 2 and wherein the power fed to a group of adjacent antenna elements from a given phase shifter is provided with an amplitude taper so that more power is fed from that phase shifter to the antenna element or elements at the centre of the group than is fed to the outer antenna elements of the group.

4. A microwave transmission system as claimed in claim 4 and wherein the power level fed to the antenna element or elements at the centre of the group is twice that which is fed to the outer elements of the group.

5. A microwave transmission system as claimed in claim 3 or 4 and wherein the output from each phase shifter is fed to a respective power divider, which feeds equal power to a plurality of hybrid networks, each hybrid network being associated with a different antenna element and being arranged to feed a predetermined power level to it.

6. A microwave transmission system as claimed in claim 5 and wherein each hybrid network receives equal power from two different power dividers, which in turn are fed from respective controllable phase shifters.

7. An aircraft landing system incorporating a microwave transmission system as claimed in any of the preceding claims.

8. An aircraft landing system as claimed in claim 7 and wherein two microwave transmission systems are provided, one being arranged to produce a microwave power which scans in elevation and the other being arranged to produce a microwave beam which scans in azimuth.

9. A microwave transmission system substantially as described with reference to Figure 4 of the accompanying drawings.

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